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ICEBERGS - WHERE THEY ARE AND WHERE THEY ARE GOING?

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INTRODUCTION

The development of offshore oil and gas on Canada's east coast in iceberg-frequented waters has reinforced the need for research and development work on icebergs. Icebergs are of particular concern to Canada's offshore oil exploration and production operations and related activities since the wells on the Grand Banks lie directly in the path of the annual North Atlantic iceberg migration route.

To protect drilling vessels, some icebergs are deflected by towing; if the icebergs are untowable, the vessel is moved. Both strategies require warning systems to provide information on approaching icebergs with sufficient lead time to take defensive action. These can be provided by reliable systems which detect iceberg locations and forecast the probable future drift path of the iceberg for the next 12 to 24 hours. Such forecasts could be applied to manage activities on an offshore site and vessel traffic around it and to maintain optimum drilling and production operations.

The projected increase of marine activity in ice-invaded waters has initiated a number of developments in remote sensing methods for ice hazard detections. Numerous advances have been made in the capability to discriminate between icebergs and multi-year and first-year ice. Many types of microwave radar systems have been applied to ice detection and classification. These include surface-mounted and airborne microwave radars, airborne and spaceborne synthetic aperture radar (SAR) and spaceborne passive microwave systems. A common feature of all these methods is their line-of-sight operation. For a surface mounted sensor, in an ocean environment, this limits the range to well

under 20 nautical miles. Airborne or spaceborne sensors have a much greater range but their coverage is limited to the periods of the over flights.

This paper describes some background information about icebergs, iceberg detection and ice forecasting systems currently under development at the Centre for Cold Ocean Resources Engineering (C-CORE). An emerging radar technology for surface-mounted ice hazard detection which uses high frequency (HF) radar waves is described. The HF band is from 3 to 30 MHz. At these frequencies electromagnetic waves are capable of over-the-horizon propagation in the ground wave mode, so that most of the radar energy follows the curvature of the earth along the air/sea-water interface. The range of detection of surface targets is thus not limited by line-of-sight operation as in microwave systems.

SOURCES OF ICEBERGS

The sources of the Labrador icebergs are the calving glaciers of west Greenland and, to a lesser degree, the glaciers of east Greenland, Devon, Ellesmere, Bylot and Baffin Islands. It is estimated that the Greenland ice cap produces between 10,000 and 30,000 icebergs each year. Of these icebergs only several hundred reach the Grand Banks of Newfoundland; the remainder break up and melt before reaching potential hydrocarbon production sites on Canada's east coast.

DRIFT PATTERNS

The distance that icebergs drift from their origin on the west coast of Greenland to the coast of Newfoundland is about 1800 nautical miles and the time required averages 2-3 years. Initially, icebergs travel in the Baffin Island current and then the Labrador current south from Hudson Strait. Finally, they

reach the Grand Banks of Newfoundland where they drift either eastward north of the Flemish cap (47°N) or southward between the Flemish Cap and the Grand Banks. Figure 1 presents the general drift pattern of icebergs and Figure 2 depicts the system of ocean currents in Baffin Bay, Davis Strait and the Labrador Sea that affect the transport of icebergs from Baffin Bay to the Grand Banks.

ICEBERG POPULATION AND FLUX

Traditionally, the severity of the iceberg season has been measured by the number of icebergs drifting south of 48°N. This is because 48°N represents the approximate northern boundary of trans-Atlantic shipping routes passing south of Newfoundland. The number of icebergs reaching the Grand Banks varies significantly from year to year (Figure 3). For example, no icebergs were sighted south of 48°N in 1966; 1,600 in 1972; 20 in 1980; 2,100 in 1984. Figure 4 shows the average number of icebergs crossing 48°N. About 94% of all icebergs crossing 48°N do so between March to July and the remaining 6% during August to February (Figure 4). For this reason the major iceberg season on the Grand Banks is considered to be from March to July.

ICEBERG SIZE CLASSIFICATION

Although icebergs are irregular in shape, the International Ice Patrol (IIP) has classified the above-water part as blocky, drydock, dome, pinnacled, tabular or growler. Table 1 presents the description of each type. Table 2 and Figure 5 present the size classification of icebergs used by the International Ice Patrol and Grand Banks operators.

ICEBERG MORPHOLOGY

Table 3 summarizes observed iceberg lengths, widths, heights, drafts, and

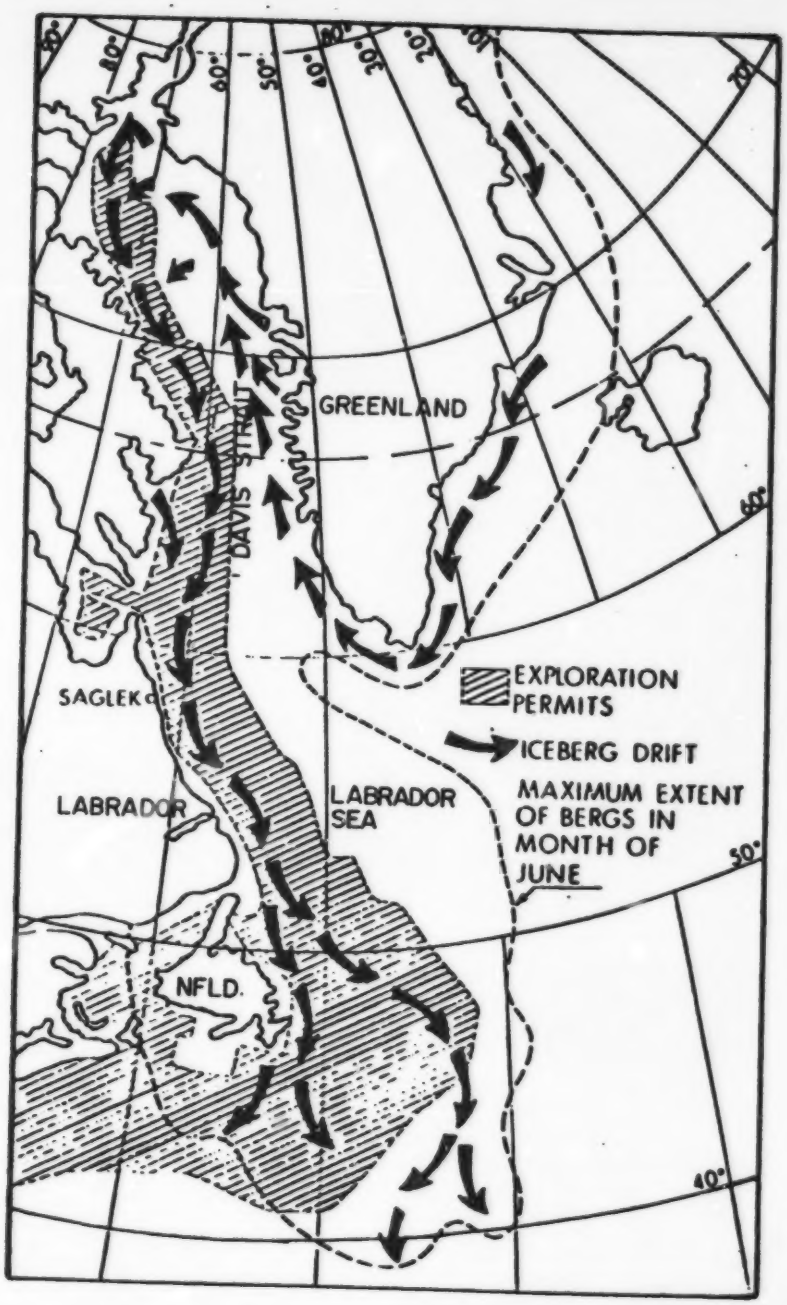


FIG. 1 GENERAL ICEBERG DRIFT PATTERN

(SOULIS, 1976)

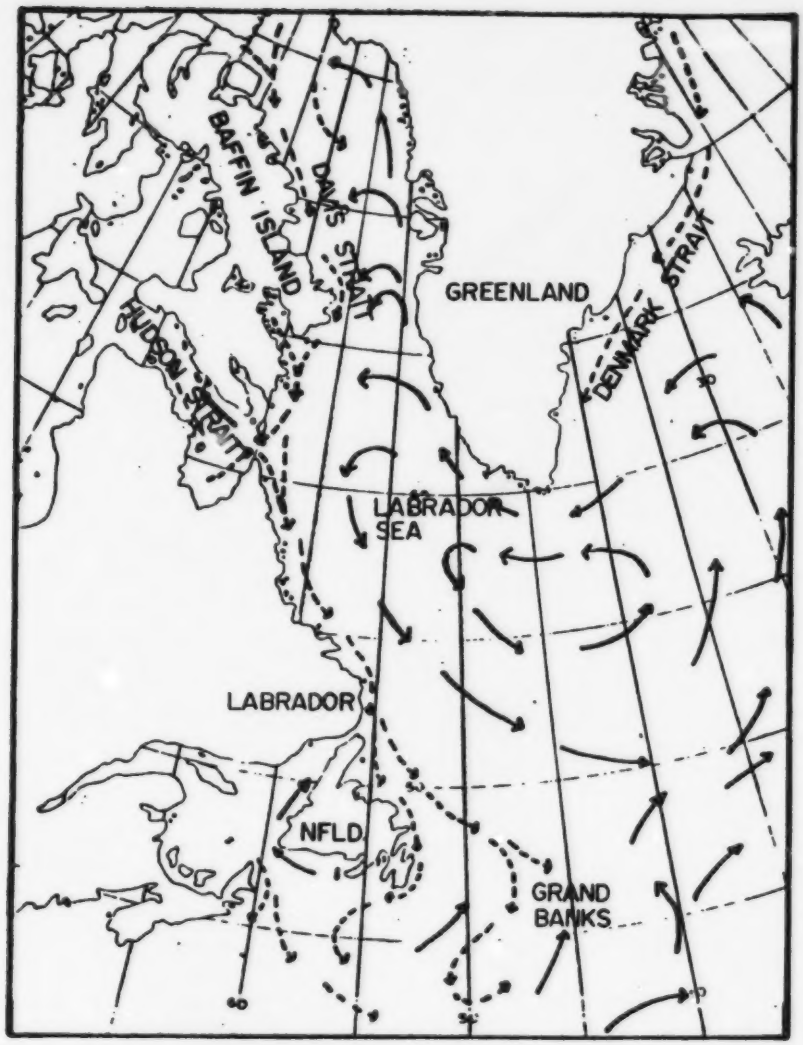


FIG. 2 THE OCEAN CURRENTS AFFECTING THE DRIFT OF ICEBERGS

(MURRAY, 1968)

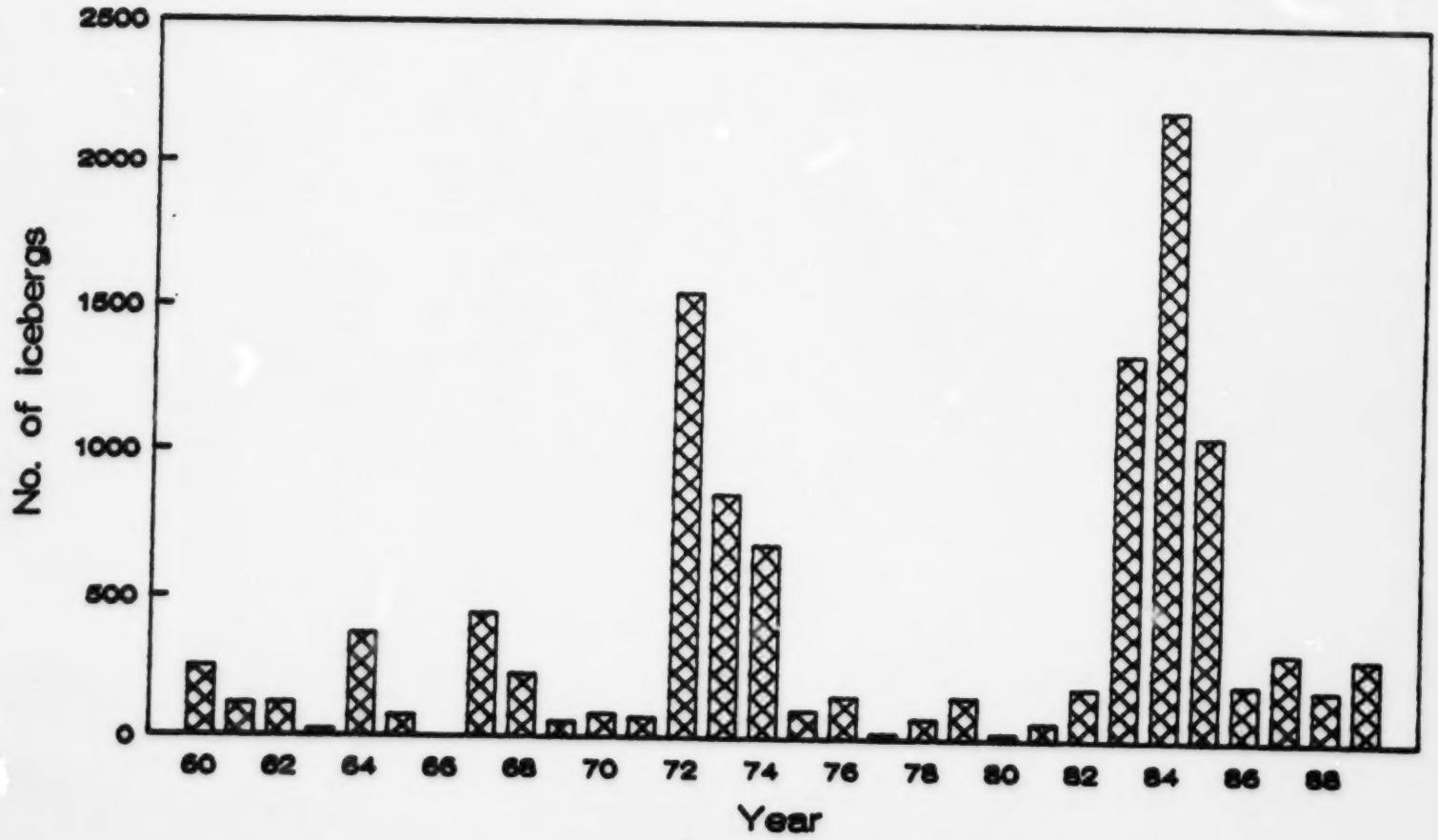


Figure 3 Number of icebergs crossing 48°N Latitude from IIP data, 1960-1989

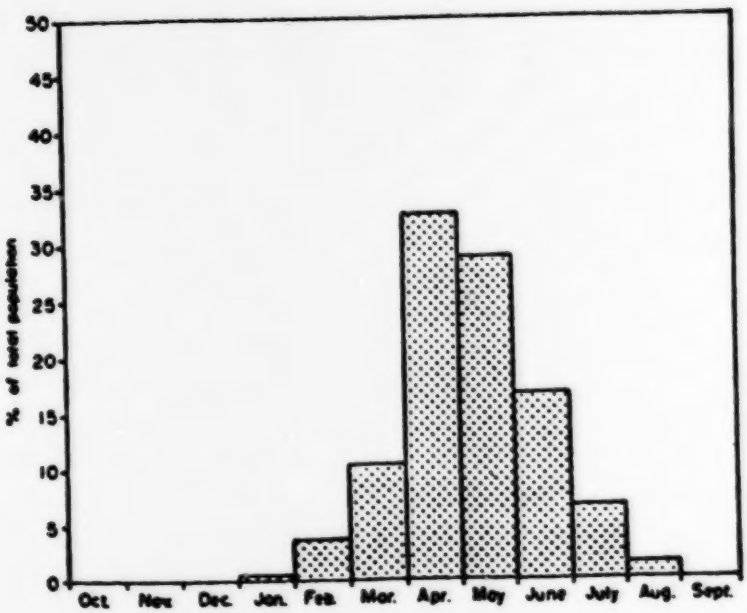
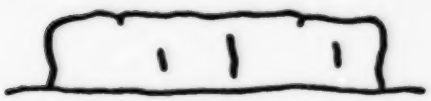


Figure 4 Monthly average of icebergs crossing 48°N latitude for 1946-1984 (U.S. Coast Guard data)



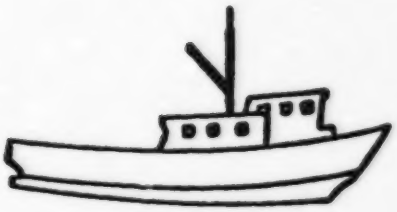
LARGE ICEBERG
LENGTH 101-200m

RIG

MEDIUM ICEBERG
LENGTH 51-100m

SUPPLY VESSEL

SMALL ICEBERG
LENGTH 16-50m



LONG LINER

BERGYBIT
LENGTH 5-15m

SURVIVAL CRAFT

GROWLER
LENGTH Less than 5m

DORY

Figure 5 Iceberg Size Comparisons.

Table 1 Above-Water Iceberg Shape Classification

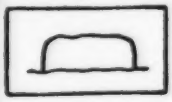
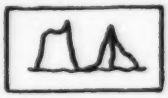
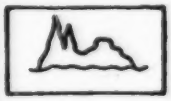
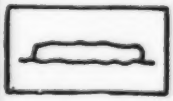
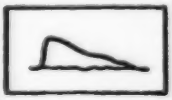
Name	I.D.Code	Description	Shape
Blocky	BLK	Steep precipitous sides with horizontal or flat top, very solid berg, length-height ratio of 3:1 to 5:1.	
Drydock	DDK	Eroded such that a large U-shaped slot is formed with twin columns or pinacles Slot extends under the waterline or close to it. Last stage of drydocked bergs are horned and winged.	
Dome	DOM	Large smooth rounded top. Solid type berg.	
Pinnacled	PNC	Large central spire or pyramid of one or more spires dominating the shape. Less massive than dome-shaped bergs of similar dimensions. These are also known as "Picturesque Greenland" type bergs.	
Tabular	TAB	Horizontal, flat-topped berg with length-height ratio of 5:1 or more.	
Wedge	WDG	A tabular iceberg which has altered is position of stability so that it now appears tilted, resembling a wedge.	
Bergy Bit	BBB	A mass of glacial ice smaller than an iceberg but larger than a growler, about the size of a survival craft.	
Growler	GGG	A mass of glacial ice that has calved from an iceberg or is the remains of an iceberg. A growler has a height of less than 1 m and a length of less than 5 m.	

Table 2 Size Classification of Icebergs used by the Grand Banks Operators (GBO) and the International Ice Patrol (IIP)

Iceberg Size	Code Used	Iceberg Height (m)	Length (m)	Approximate Weight (tons)
Growler	GG	under 1	under 5	1,000
Bergy Bit	BB	1-5	5-15	10,000
Small	SB	5-15	15-60	100,000
Medium	MB	16-50	60-120	2,000,000
Large	LB	51-75	120-220	10,000,000
Very Large	VB	over 75	over 220	over 10,000,000

Note: In IIP size classification, growlers and bergy bits are combined under 'growlers'.

Table 3 Summary of Iceberg Dimensions, Grand Banks

Variable	Mean	S.D.	Minimum	Maximum	No. of Observations
Length (m)	63	57	3	360	243
Width (m)	40	34	2	152	236
Height (m)	17	16	1	100	240
Draft (m)	49	28	6	162	243
Mass(tonnes)	254,872	608,552	18	4,060,724	232

masses in the Grand Banks region. The average length was observed to be 63m and the maximum was 360m. The average height was 17m with the maximum being 100m. The average mass was 255,000 tonnes and the maximum was 4,000,000 tonnes. Figures 6 and 7 show the frequency distributions of these parameters.

ICEBERG DRIFT SPEED

Iceberg speed data is estimated from radar which is used to track icebergs on the Grand Banks. The drift speed is computed from the changing observed positions, usually about 1 hour apart. A total of 1,957 iceberg speed data points were calculated for 237 icebergs tracked in 16 drill sites over a period of 4 years (1984-1987). Table 4 presents the statistics on the distribution of the above mentioned icebergs speeds.

TABLE 4

Summary of Iceberg Drift Speed

Iceberg Speed Parameter	Grand Banks Area
Mean (m/sec)	0.35
S.D.	0.24
Minimum (m/sec)	0.00
Maximum (m/sec)	1.36
No. of Icebergs	237

REMOTE SENSING OF ICEBERGS

Extensive research at C-CORE and the Faculty of Engineering and Applied Science over the past ten years has contributed to the development of HF radar systems as a remote sensing tool in the ocean environment. One of the primary

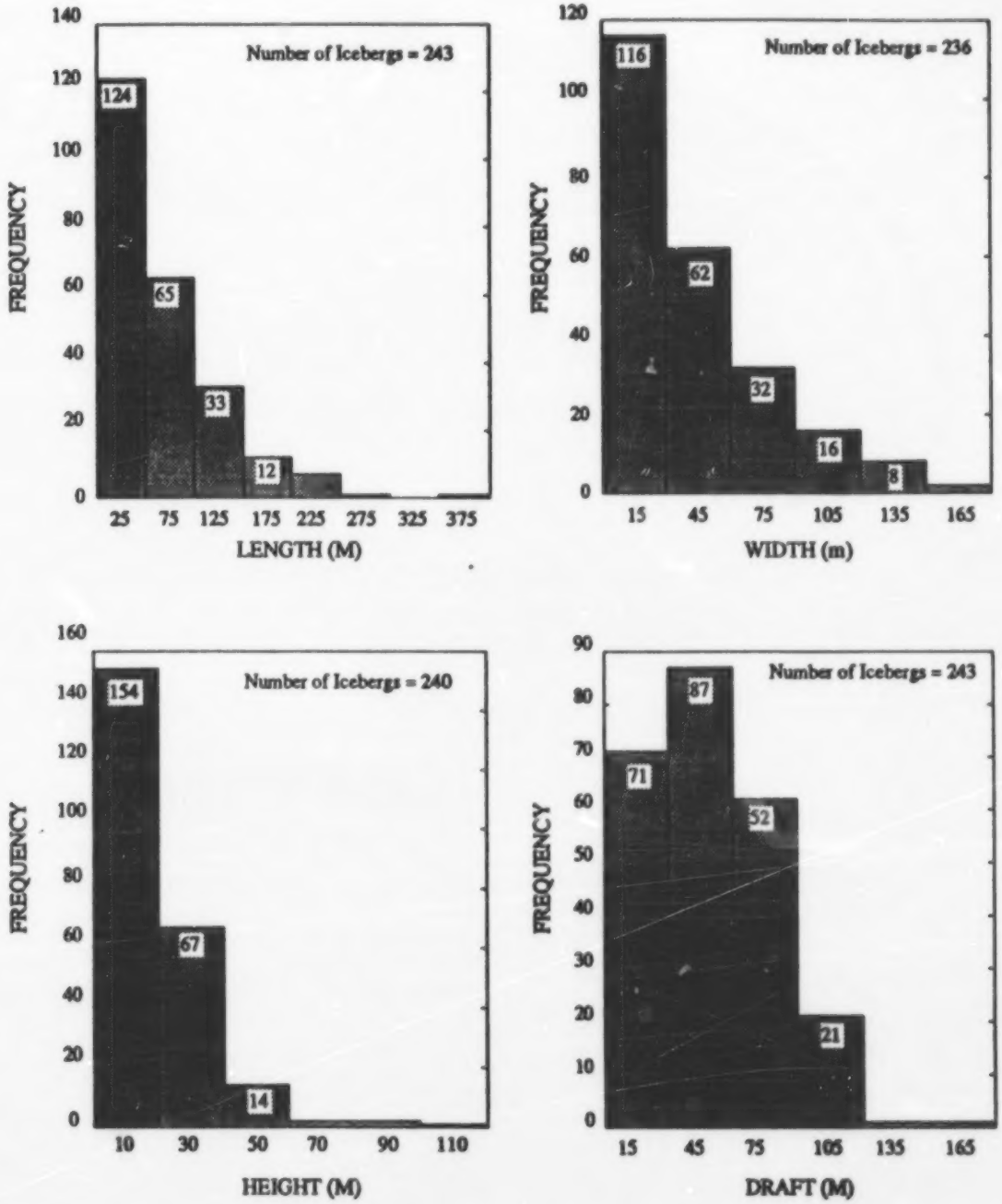


Figure 6. Distribution of iceberg length, width, height and draft for all icebergs tracked by radar from 16 drilling sites on the Grand Banks during the period of 1984 to 1987.

thrusts of the initial research was to investigate the electromagnetic interaction between the ice cover and the ocean surface, and to apply this research to modelling both the signal return and the behaviour of HF radars as remote sensors. In other words, the radar returns from different kinds of targets, including icebergs, can be predicted analytically and the effects of interfering signals, such as noise and ocean clutter, can be taken into consideration.

The ice detection aspect of the research was supported by the offshore resource development industry. A device capable of detecting and tracking sea-ice and icebergs more reliably and with greater range than available surface-mounted microwave equipment was viewed as being extremely useful to offshore industry. The ice detection program initiated at C-CORE to develop that capability has investigated the theoretical models for iceberg detection with HF radar. One of the conclusions of the earlier studies was that icebergs present a sizable target for this kind of radar and that ocean clutter was the dominant factor limiting the maximum detectable range and the minimum detectable iceberg size. Subsequent research work has led to a better understanding of the clutter signals; techniques have been developed to increase the target-to-clutter signal ratios substantially, thereby improving the range and reliability of iceberg detection.

The analytical research work was complemented by extended field experiments conducted with a commercial HF radar system. Two Coastal Ocean Dynamics Application Radars (CODAR), originally developed for ocean current measurements, were modified for experimental data collection using surface targets such as ships and icebergs. Experimental verification of the analytical models has been

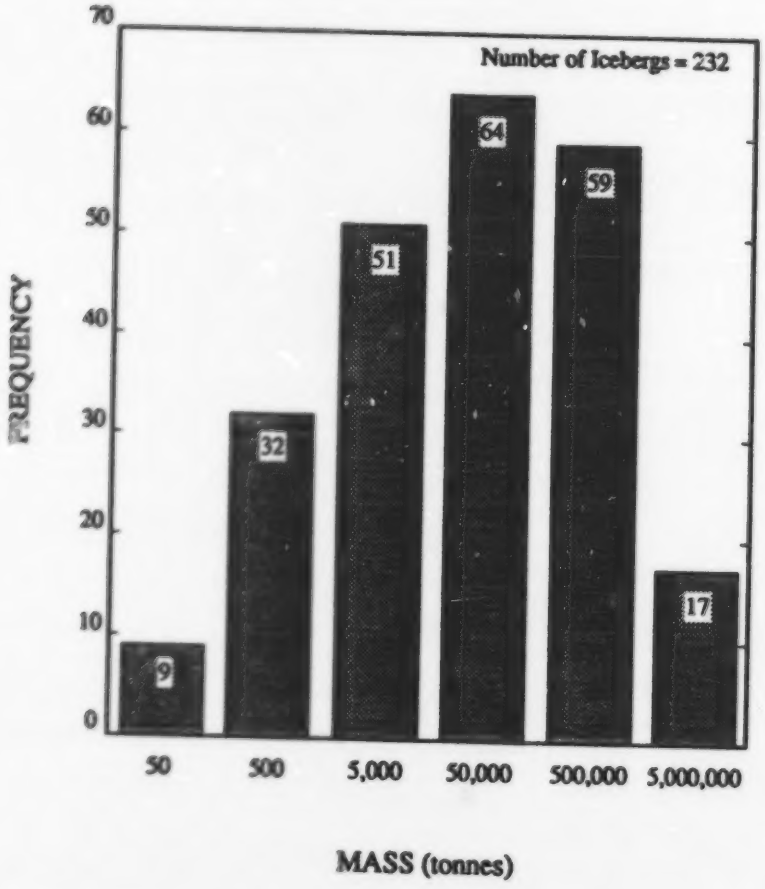


Figure 7. Distribution of estimated iceberg mass for all icebergs tracked by radar from 16 drilling sites on the Grand Banks during the period of 1984 to 1987.

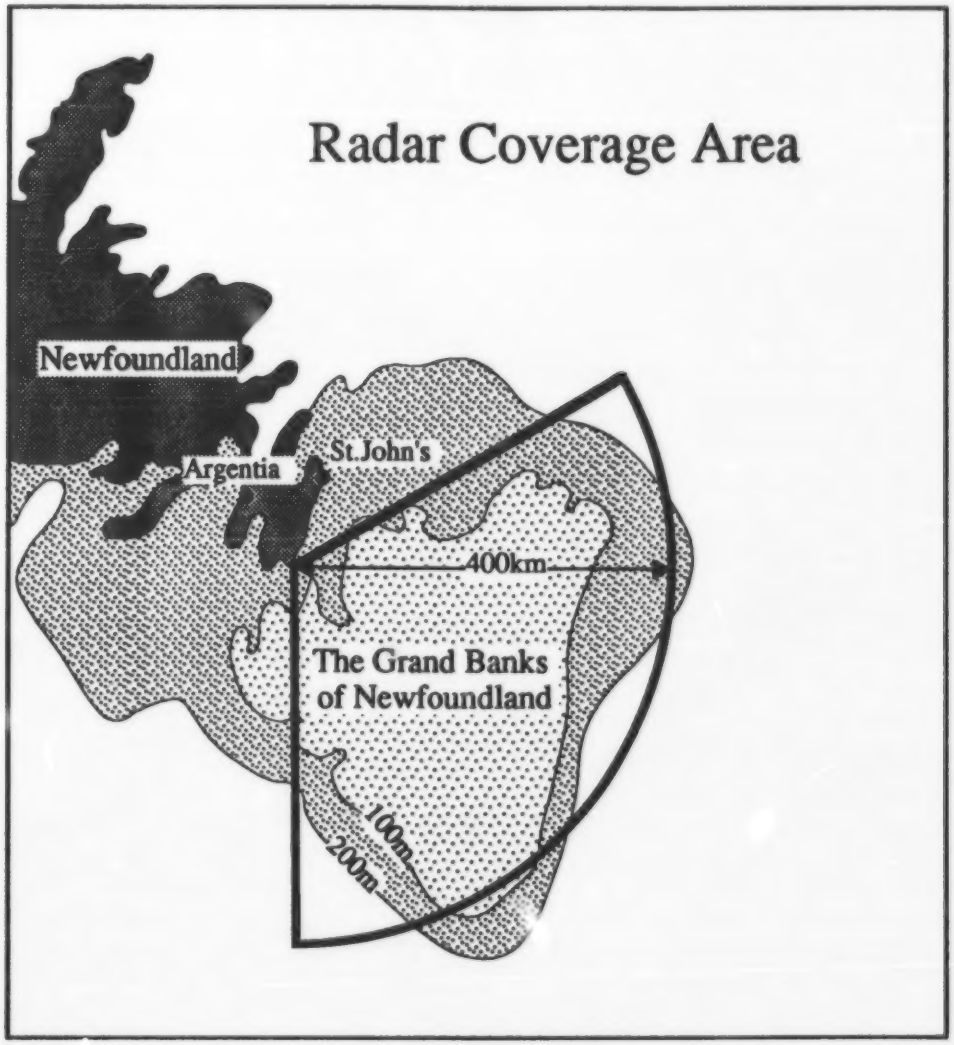


Figure 8 Region map indicating the site and the predicted radar coverage area.

achieved under a variety of conditions, including rig-based operation, and has established a high confidence level for the theoretical predictions.

A new Canadian company, Northern Radar Systems Limited, has been formed to commercialize this technology. Northern Radar is currently building a prototype HF radar at Cape Race, at the south-east tip of the Avalon Peninsula, for the long range detection of ships, icebergs and for ocean environmental monitoring. This installation demonstrates the viability of HF radar as a reliable surveillance device under operational conditions. The flexible design of the radar will allow rapid and efficient evaluation of analytical models for target detection and tracking and will be used to optimize the designs of application oriented operational systems. Figure 8 shows the location of the Northern Radar facility at the south-east tip of the Avalon Peninsula from which it has the radar coverage capacity extending over the offshore oil-fields such as Hibernia. With a maximum range of 400 km and steerable over a 120 degree sector, the device will have a surveillance capability over a 250,000 km^2 area. A more detailed layout of the radar site 'dominated by the 880 metre long receive antenna array' is shown in Figure 9. This facility is expected to be operational by July 1990 and, will monitor vessel traffic, and ice and ocean environmental conditions.

In addition to the large shore based HF system, C-CORE is also involved in developing a compact transportable HF radar system for operation on floating platforms such as ships and oil-rigs. The compact size will limit the dimensions of the antenna and the directionality, i.e. there will be a higher uncertainty in the direction of a target. The motion of the floating platform and the proximity of metallic structures to the antenna system introduce other problems

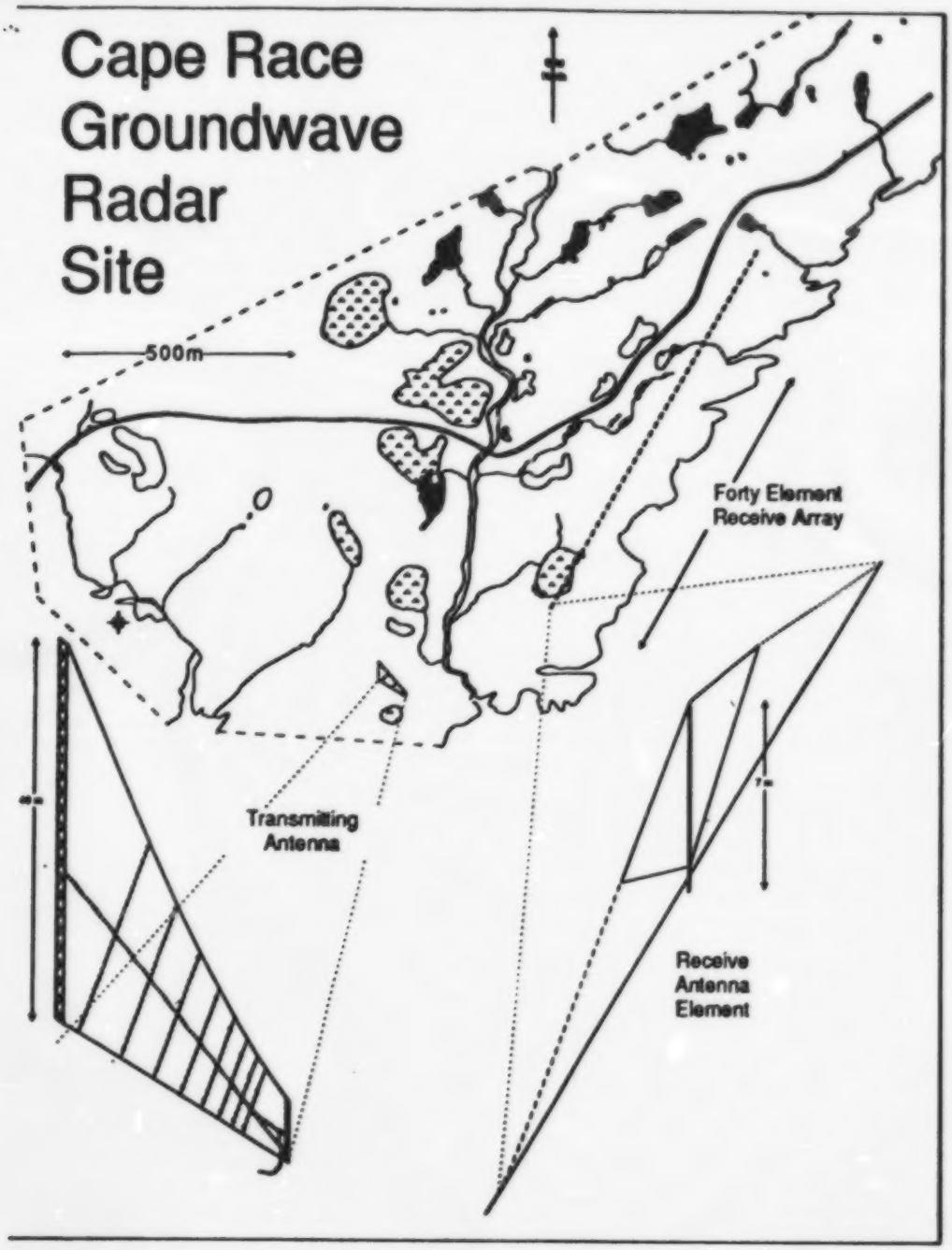


Figure 9 A more detailed layout of the site, showing the location and proportions of the transmitting and receiving antennas.

not encountered on a shore-based facility. These problems have been investigated and compensating techniques have been developed. The practical implementation and field testing of such a compact system is foreseen in the near future.

FORECASTING ICEBERG DRIFT

Reliable iceberg detection will furnish the initial data for the iceberg forecast system. These data will then be used as input for the model which describes iceberg motion and accounts for the various factors which dictate iceberg drift. Field observations and theoretical studies (eg. Murray 1968, El-Tahan 1980, Mountain 1980) suggest that, in general, iceberg drift is affected by:

- Currents;
- Winds;
- Coriolis acceleration;
- Waves;
- Ocean surface slope (pressure gradient); and
- Iceberg size parameters.

The effect of these factors on iceberg drift is described in detail in El-Tahan *et al.* (1983) and El-Tahan (1987) and is briefly summarized below. Currents are the prime driving force in iceberg drift contributing about 50% to 65% of the total iceberg movement. The current is made up from many components that vary significantly with time and space. Wind affects icebergs in two ways: directly by exerting force on the above water portion of the iceberg, and indirectly by generating waves and surface current. Coriolis force is directly

or indirectly responsible for the looping and spiralling motions of some icebergs. In addition, sea state can have significant effects on iceberg drift when large waves are involved. The drift of an iceberg is also affected by its size and shape. Large icebergs were observed to be influenced by deep currents while small bergs were more sensitive to surface currents. Icebergs with high sails are more affected by wind than bergs with low sail heights. The draft of an iceberg also affects its motion. An iceberg entering an area with water depth less than its draft will be grounded until the draft is reduced by melting (El-Tahan, 1986) or overturning. Studies on long term tracking of icebergs indicate that icebergs can be grounded for more than 70% of observation time (El-Tahan *et al.* 1985).

The Canada/Newfoundland Offshore Development Fund awarded a grant to C-CORE and CORETEC Incorporated to develop an operational Integrated Sea Ice/Iceberg Forecast System (IIFS). The system is based on models for regional and site specific forecasting pertaining to iceberg trajectory (ICEBERG), iceberg ensembles drift (ENSEMBLES) and sea ice edge drift (ICEEDGE) (Figures 10 and 11).

The models used to predict iceberg and sea ice drift are based on the dynamic model developed by El-Tahan (1980). The iceberg drift model has been extensively used both for hindcast analysis of iceberg trajectories and prediction of iceberg drift in support of offshore drilling operations. The sea ice edge drift model has also been used operationally during the drilling seasons 1986 to 1989.

Forces considered by the models are those due to wind, currents, waves, coriolis effects and pressure gradients. When appropriate the models account

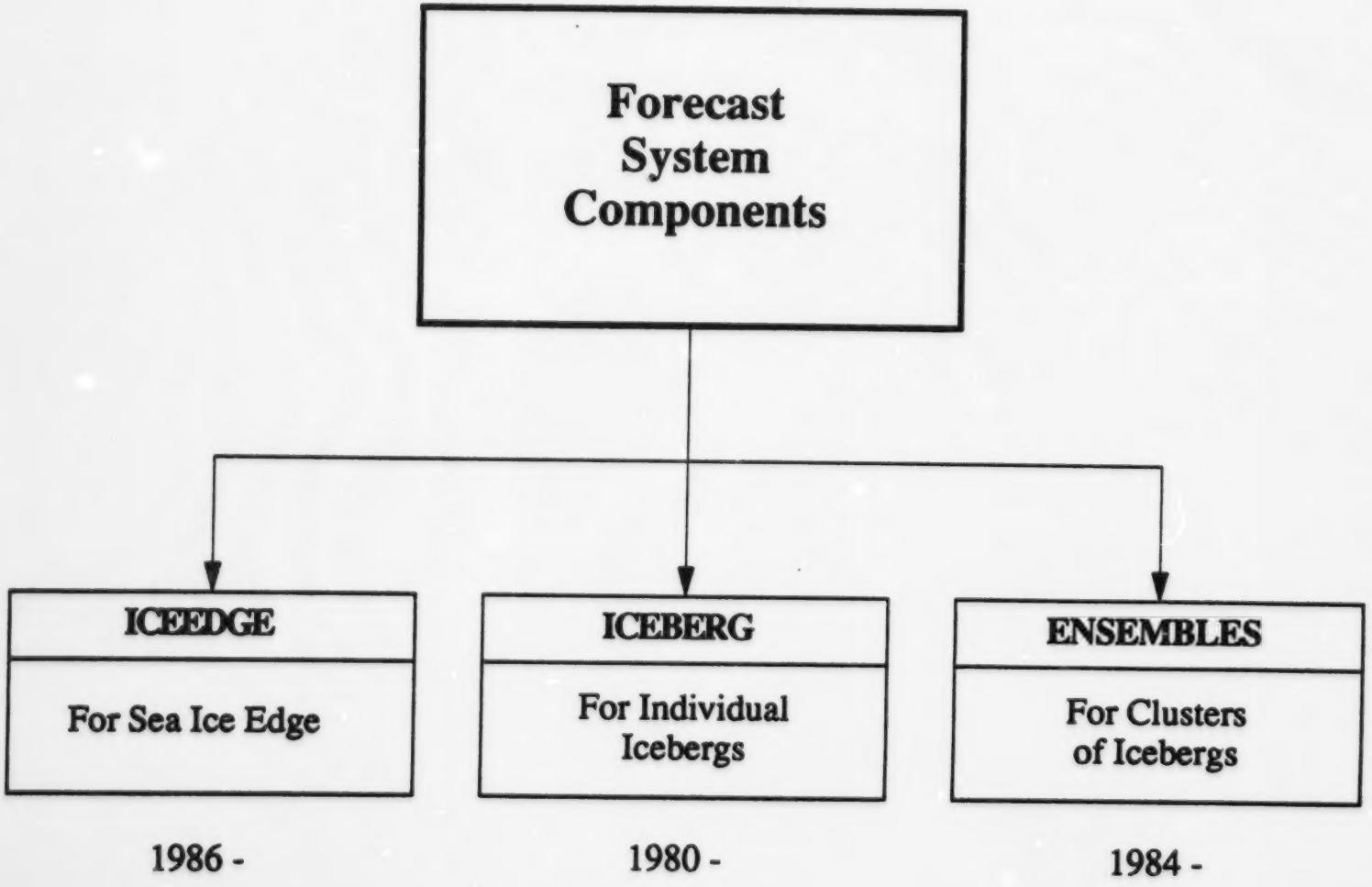


Figure 10 Components of the Integrated Sea Ice/Iceberg Forecasting System (IIFS)

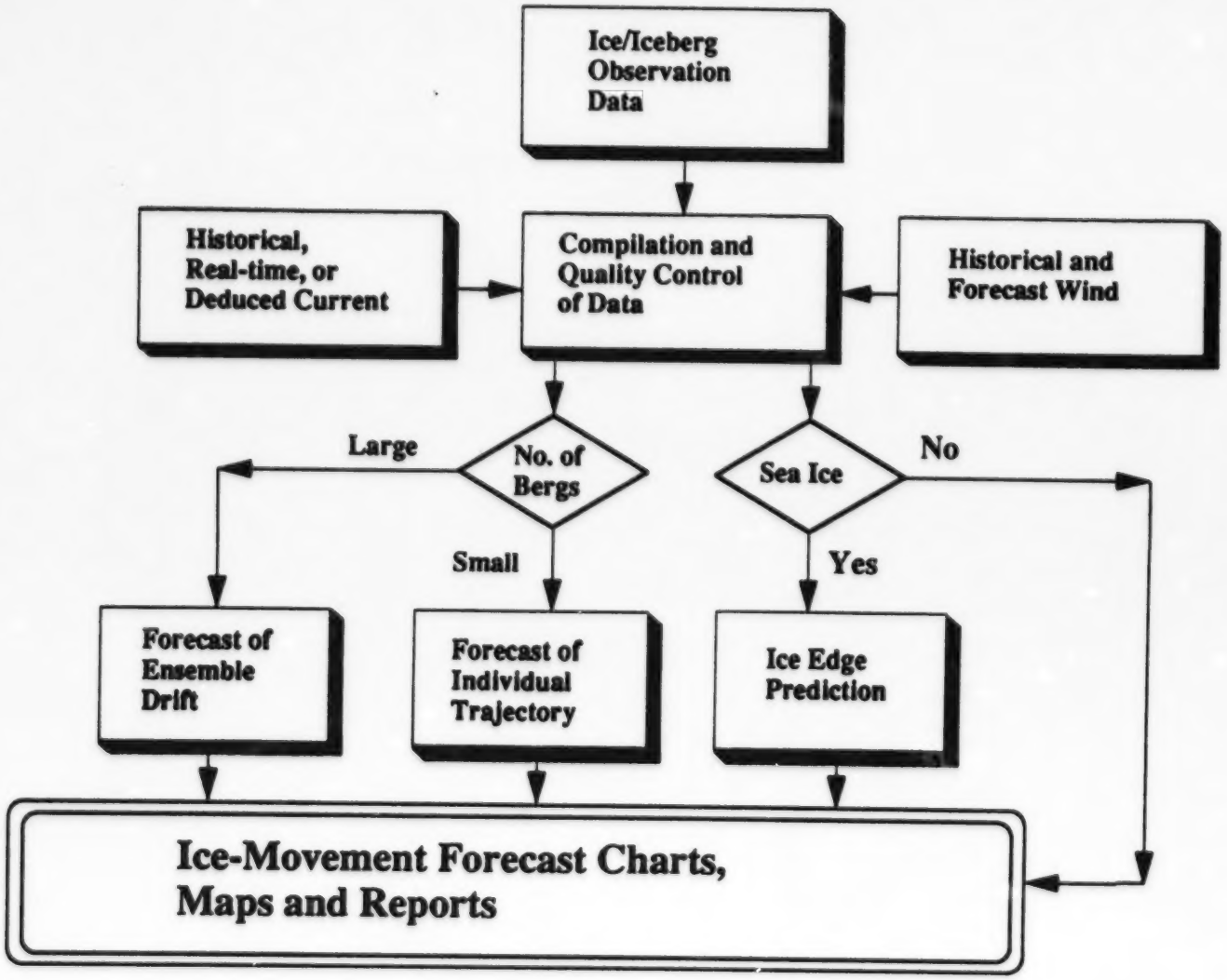


Figure 11 Sea Ice/Iceberg Forecast System (IIFS)

for current variations with depth. The model predictions have been tested against field data and subjected to continuous improvements. The physics of the model are known to the extent that good predictions of iceberg trajectories can be made for periods of more than 40 hours (El-Tahan, 1980). This can be done even under storm conditions, provided that detailed wind and current data are available as input to the model.

The development of an Integrated Sea Ice/Iceberg Forecast System (IIFS) will be carried out in three (3) phases. The first phase will upgrade the sea ice edge model. The second phase will complete improvements to the iceberg models (individual and ensembles). The third phase will involve the conceptual design and the implementation for the IIFS. The system will also include the necessary data bases and will incorporate and use a computer data base management system.

Intensive effort, further evaluation and refinement will be undertaken before the system reaches its operational phase . Upon completion, the proposed system will be the first of its kind. It could have continuous updating of observed iceberg and ice edge positioning by ground wave remote sensing radar. It will provide detailed site specific forecasts suited to client needs. This venture to provide an ice hazard warning system will complement the Ice Data Integration and Analysis System (IDIAS), which is currently under development by the Atmospheric Environment Service (AES).

CONCLUSION

Offshore operators have already recognized the significant probability of

iceberg structure collisions in the Grand Banks region. Exploration drilling and production development plans incorporate ice management as an important part of the marine operations. Ice detection and tracking, and ice forecasting will be critical components of such a management system. The C-CORE 5 year research plan addresses both topics and has a time schedule to produce solutions that are in conformity with industry's proposed development schedules:

- **Improvement for Iceberg Detection:** Basic research has demonstrated that ground wave radar will identify icebergs at over-the-horizon ranges. The work is proceeding with the engineering design to implement this research. The target is a rig and vessel mounted iceberg warning and tracking radar.

- **Operational Iceberg Forecasting:** An iceberg drift model is being adapted to provide forecasts that predict future tracks for observed icebergs. The immediate goal is to predict tracks for 36 to 48 hours. The valid forecast period will continue to improve as forecasts for the driving forces improve.

C-CORE is committed to the integration of the results of these systems in its research thrusts. Iceberg positions and ocean wave and current maps acquired by the ground wave system will be employed to continually update the initial condition of the iceberg forecast model. The result will be the best ice information available in real time and will help operators proceed with safe and economical offshore resource development.

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